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Research Paper

The Influence of Coal Characteristics on Coke Formation in Indonesia's Steel Industry

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Abstract
Indonesia possesses abundant coal resources with diverse characteristics, which directly influence their potential in the steel industry, particularly in metallurgical coke production. Coke serves as both a reducing agent and a crucial fuel in the blast furnace process, requiring specific coal qualities such as high fixed carbon content, low sulfur content, good caking ability, and sufficient thermoplastic properties. However, Indonesian coal is predominantly sub-bituminous and lignite, which are limited for coking purposes. This paper examines the influence of coal characteristics on coke formation, evaluates the potential of Indonesian coal, including coking coal prospects in Muara Teweh, Central Kalimantan, for metallurgical applications, and reviews strategies for enhancing coal utilization to achieve competitive coke production. Furthermore, the role of Environmental, Social, and Governance (ESG) principles in developing a sustainable coke industry is also discussed. Findings suggest that enhancements in beneficiation processes, coal blending strategies, and ESG integration can improve domestic coke self-sufficiency while promoting sustainable development.

Keywords: *Coal characteristics, coal qualities, ESG, metallurgical coke, steel industry*

INTRODUCTION

Indonesia is one of the world's largest coal producers with significant annual production for both domestic and export markets. Nevertheless, the utilization of coal in downstream sectors—particularly in the steel industry—remains relatively limited compared to its use in power generation. Coke functions as a reducing agent, an energy source, and a burden support material in the blast furnace; its quality is determined by coal characteristics, particularly fixed carbon content, volatile matter, plasticity (maximum fluidity), maceral composition (vitrinite content), as well as ash and sulfur levels (Speight, 2020). Bituminous coal with good caking ability is generally required to produce high-quality metallurgical coke.

In the Indonesian context, most coal resources are of low rank (sub-bituminous to lignite), which tend to have low plasticity and high volatile matter, making them less ideal for coking without prior treatment or blending. However, several studies indicate the existence of coking coal prospects in Central Kalimantan, particularly in the Muara Teweh area within the Barito Basin. Geological and coal quality studies in parts of the Tanjung Formation indicate medium– to high–volatile bituminous coal with maximum fluidity values relevant for coke formation (Wiranata et al., 2020).

The utilization of coking coal in the Barito Basin highlights the presence of metallurgical coal resources that can be developed for both domestic and export markets (Cokal Limited, 2020; Sustainable-Carbon, n.d.). The availability of coal supply along the Barito River corridor is strategically advantageous for logistics (Global Energy Monitor, n.d.). Moreover, recent regional

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geological studies in the Barito Basin confirm the presence of thick and continuous Eocene coal seams, forming a strong basis for metallurgical coal development prospects (Fikri et al., 2022).

In line with this, research developed in the Sekako–Teweh Tengah area, North Barito Regency, reports coal quality evaluations that classify certain seams as “coking coal” (Rahmiyanti, 2024). Although further pilot-scale verification and complete coking tests are required, the accumulation of findings supports the argument that Muara Teweh holds promising coking coal potential, which can be advanced through technical strategies such as beneficiation, carbon pre-treatment, stamp charging, and especially coal blending schemes to meet metallurgical coke specifications.

From a policy and governance perspective, coal downstreaming agendas and the need for coke import substitution for the steel industry are key drivers. The integration of Environmental, Social, and Governance (ESG) principles is essential from upstream (mining) to downstream (coking and utilization) to reduce emissions, ensure occupational health and safety, and guarantee supply chain transparency and accountability to stakeholders. Thus, strengthening domestic coke production by leveraging Muara Teweh’s potential presents an opportunity to enhance Indonesia’s steel industry self-reliance while aligning with the Sustainable Development Goals.

This research aims to determine whether coal in the study area can be utilized as coking coal based on the results of coal characteristic tests from samples taken in Muara Teweh, Central Kalimantan.

LITERATURE REVIEW

Coke is one of the most important materials in the steel industry, functioning as fuel, a reducing agent, and a structural support material inside the blast furnace. The key properties of coke that determine its performance include mechanical strength, resistance to high temperatures, and chemical reactivity, commonly expressed through the Coke Reactivity Index (CRI) and Coke Strength after Reaction (CSR) (Kumar et al., 2022). Coke quality is strongly influenced by the characteristics of the parent coal, especially fixed carbon content, volatile matter, maceral composition, plasticity, ash, and sulfur content (Speight, 2020). Coal with high vitrinite content and suitable maximum fluidity values tends to produce coke with better mechanical strength (Rantitsch et al., 2020). Conversely, high ash and sulfur contents reduce coke quality and increase steel processing costs (Wang et al., 2023).

Several studies emphasize that coke formation is influenced by the thermoplastic behavior of coal during heating. Jin et al. (2021) demonstrated that organic composition and thermal parameters significantly affect coke yield and microstructural evolution. The microstructural evolution of coke during carbonization is also a crucial factor, as coke particle heterogeneity directly correlates with variations in CRI/CSR values and mechanical strength (Rantitsch et al., 2020). Therefore, a deep understanding of coal rheological properties—such as maximum fluidity, swelling index, and vitrinite reflectance (Rvmax)—is essential for evaluating coking coal quality (Wiranata et al., 2020).

Although Indonesia is known as one of the world’s largest coal producers, most of its reserves are dominated by low-rank coals (sub-bituminous and lignite), which are limited as coking coal feedstock. However, there are coking coal prospects, one of which is in Muara Teweh, Central Kalimantan. Geological studies in the Barito Basin, particularly in the Tanjung Formation, indicate the presence of bituminous coal with medium to high volatility and thermoplastic properties, which are suitable for coke formation (Wiranata et al., 2020; Fikri et al., 2022). Academic studies in the Sekako–Teweh Tengah area also indicate the existence of seams with coking coal potential (Rahmiyanti, 2024). Furthermore, the Bumi Barito Mineral (BBM) project in Muara Teweh has identified metallurgical coal resources that are viable for both domestic and export markets (Cokal

Limited, 2020; Sustainable-Carbon, n.d.). These facts demonstrate that Indonesia does not necessarily have to depend entirely on coke imports if such potential can be optimized through appropriate technological development.

To overcome the limitations of domestic coal quality, widely studied strategies include coal blending and beneficiation. Zhang et al. (2020) emphasized that blending coals with different characteristics can produce formulations that meet coke specifications, even when one component has low caking properties. Liu et al. (2024) further developed predictive models using algorithms to optimize coal allocation, thereby maintaining coke quality at minimal cost. In addition, beneficiation methods such as froth flotation (Usman et al., 2022) and dry techniques, including sensor-based sorting (Hughes et al., 2024), have proven effective in improving coal quality prior to coking. Another alternative is producing semi-coke or formed coke from low-rank coal through partial carbonization and briquetting processes (Guo et al., 2023), which can serve as a partial substitute for metallurgical coke.

Coke utilization in Indonesia's steel industry still heavily depends on imports, with over 70% of its demand supplied by other countries (Mochizuki, 2019). Meanwhile, national steel consumption continues to rise in tandem with the development of infrastructure and industrial growth. The potential substitution of imports with domestic coke from regions such as Muara Teweh would have a significant impact on energy security, cost efficiency, and steel industry independence. Moreover, in the context of sustainability, literature highlights the importance of integrating ESG principles in coke development. Li et al. (2024) demonstrated that coke with varying reactivity can be partially substituted with alternative carbon materials to reduce emissions. In contrast, the recommended lignin and biochar as long-term options to support the decarbonization of the steel industry. Thus, strengthening domestic coke production in Indonesia, particularly by utilizing the metallurgical coal potential in Muara Teweh, not only supports the steel industry's independence but also aligns with global commitments to sustainable development.

RESEARCH METHOD

This study was conducted in the Muara Teweh coal mining area, North Barito Regency, Central Kalimantan, located within the Barito Basin, which is recognized for its coking coal potential. The location was chosen based on previous geological studies indicating the presence of bituminous coal seams with thermoplastic properties suitable for coke feedstock (Wiranata et al., 2020; Fikri et al., 2022; Rahmiyanti, 2024). Sampling was conducted purposively on several prospective seams, taking into account variations in depth and local geological conditions. Several coal samples were collected from the study area and further processed in the laboratory.

The collected coal samples were first air-dried at room temperature, then crushed and sieved to a fine powder to achieve homogeneity before analysis. Analytical procedures followed international standards (ASTM and ISO), commonly used in testing coal quality for coke production. Proximate analysis was conducted to determine moisture, volatile matter, ash, and fixed carbon contents, while ultimate analysis determined elemental composition (carbon, hydrogen, nitrogen, sulfur, and oxygen). These parameters are crucial in evaluating the suitability of coal as a coking feedstock. Additionally, coal plasticity was evaluated using the Free Swelling Index (FSI), Gieseler plastometer, and Roga Index methods to measure swelling capacity, plastic range, and coke strength.

Petrographic analysis was also performed to determine maceral composition, the proportion of vitrinite, inertinite, and liptinite, as well as vitrinite reflectance (Rvmax), which indicates coal maturity. The next stage involved laboratory-scale carbonization tests, in which samples were heated to 1000 °C in a closed furnace to produce coke. The coke products were then tested for durability using the Coke Reactivity Index (CRI) and Coke Strength after Reaction (CSR) measurements, as per ISO 18894 standards.

All test results were analyzed descriptively and compared with international coking coal quality standards as well as the characteristics of imported coal currently used in Indonesia's steel industry. This analysis aimed to assess the feasibility of Muara Teweh coal as coking feedstock, either directly or through alternative approaches such as coal blending or semi-coke production. With this methodological approach, the research is expected to provide a comprehensive overview of the potential use of Muara Teweh coal in supporting the national steel industry's self-sufficiency.

FINDINGS AND DISCUSSION

Indonesia possesses abundant coal resources, with total resources of 97.96 billion tons and reserves of 31.95 billion tons (Badan Geologi, 2025). One of the promising coal-producing regions is Central Kalimantan, particularly Muara Teweh within the Tanjung Formation. This Late Eocene formation, about 1,300 meters thick, consists of alternating sandstones, shales, siltstones, conglomerates, limestones, and coal layers deposited in a littoral to swamp environment. Its complex geology, influenced by Miocene–Pliocene inversion tectonics and structural deformations, along with subsurface seismic data indicating uplift and igneous intrusions, suggests enhanced coal maturity (Satyana et al., 1997). Consequently, Muara Teweh coal is considered to have favorable qualities for coking coal development and holds strategic potential for strengthening Indonesia's steel industry.

The results of the proximate analysis demonstrate that the mean ash content is 8.89%, and the mean total moisture content is 3.5%. The average fixed carbon content is 54.15%. The average volatile matter value is 35.53%, and the average fuel ratio value is 1.52. The average sulfur content of the samples was found to be 0.51%. The comprehensive outcomes of the proximate analysis and total sulfur testing are presented in Table 1.

Table 1. Proximate analysis and total sulfur results

NO	Sample ID No.	Total Moisture % (ar)	Ash % (adb)	Volatile Matter % (adb)	Fixed Carbon % (adb)	fuel ratio	Total Sulphur % (adb)
1	T8.02442	3.42	8.9	34.08	55.96	1.64	0.31
2	T8.02443	3.6	8.81	35.99	53.56	1.49	0.48
3	T8.02457	3.47	8.95	36.53	52.92	1.45	0.73
Average		3.50	8.89	35.53	54.15	1.52	0.51

The coking coal parameters analyzed included CSN, MF, HGI, CRI, and CSR. The mean CSR value obtained was 8.17. The mean MF value obtained was 26,980 ddpm. The mean HGI value was 57.33. Concurrently, the mean CRI and CSR values were 21.28% and 52.38%, respectively. The comprehensive outcomes of the coking coal parameter testing are presented in Table 2.

Table 2. Coking Coal Parameter Test results

NO	Sample ID No.	CSN Point	MF ddpm	HGI	CRI %	CSR %
1	T8.02442	8.5	38346	58	26.03	40.26
2	T8.02443	8	25986	58	16.18	66.66
3	T8.02457	8	16608	56	21.62	50.22
	Average	8.17	26980.00	57.33	21.28	52.38

According to international standards (Speight, 2020), the characteristics of metallurgical coking coal generally fall within specific parameter ranges. Fixed carbon (FC) content should be greater than 58%, while volatile matter (VM) is typically within the range of 18–35%. The ash content is expected to be below 10%, and the sulfur (S) content should be less than 1%. The fuel ratio (FC/VM) is considered acceptable if it exceeds 1.5. The Free Swelling Index (FSI) or Crucible Swelling Number (CSN) must be equal to or greater than 6 for coking coal, with values between 8 and 9 indicating hard coking coal. In terms of rheological properties, the maximum fluidity (MF) of prime coking coal generally ranges from 5,000 to 30,000 ddpm. Reactivity and strength indices are also crucial, with the Coke Reactivity Index (CRI) ideally ranging between 20% and 30%, and the Coke Strength after Reaction (CSR) exceeding 50%.

Table 3. Comparison of Muara Teweh coal analysis results with metallurgical coking coal standards

Parameter	Muara Teweh Average Result	Metallurgical Coking Coal Standard*	Compliance
Fixed Carbon (FC, %)	54.15	> 58	Slightly below standard
Volatile Matter (VM, %)	35.53	18 – 35	Slightly higher
Ash (%)	8.89	< 10	Compliant
Sulfur (S, %)	0.51	< 1	Compliant
Fuel Ratio (FC/VM)	1.52	> 1.5	Compliant (lower bound)
CSN (Crucible Swelling No.)	8.17	≥ 6 (coking coal); 8–9 (hard coking)	Highly compliant
Maximum Fluidity (MF, ddpm)	26,980	5,000 – 30,000	Compliant
HGI (Hardgrove Index)	57.33	50 – 70 (typical for coking coal)	Compliant
CRI (%)	21.28	20 – 30	Compliant
CSR (%)	52.38	> 50	Compliant

In general, Muara Teweh coal exhibits qualities that are close to international metallurgical coking coal standards, particularly due to its high CSN value, low sulfur content, and adequate CSR performance. The only notable shortcomings are its slightly lower fixed carbon content and relatively higher volatile matter compared to the standard benchmarks. Nevertheless, these limitations can be addressed by using coal blending technologies with other coals that have a higher fixed carbon content. Therefore, Muara Teweh coal holds significant potential to be developed as a domestic coking coal source, either for direct utilization or through blending schemes to meet the demands of Indonesia's steel industry. Moreover, when aligned with Environmental, Social, and Governance (ESG) principles, the development of Muara Teweh coking coal can support sustainable industrial practices by reducing dependence on imports, ensuring responsible mining operations, minimizing environmental impacts through the use of cleaner coal technologies, and enhancing socio-economic benefits for local communities. This integration strengthens its strategic role not only in securing energy and raw material supply for the steel sector but also in supporting Indonesia's commitment to sustainable development and global decarbonization efforts.

CONCLUSIONS

Muara Teweh coal exhibits qualities comparable to international metallurgical coking coal, particularly due to its high CSN, low sulfur content, and sufficient CSR. Minor shortcomings in fixed carbon and volatile matter can be mitigated through coal blending, making it a promising domestic source for reducing import dependency and strengthening Indonesia's steel industry. When developed with ESG principles, it can support sustainable mining and deliver socio-economic benefits.

LIMITATIONS & FURTHER RESEARCH

The research limitations of this study lie in the restricted number of samples analyzed, which may not fully reflect the heterogeneity of coal seams in the Barito Basin. Furthermore, the scope of the investigation was confined to laboratory-scale analyses, without pilot-scale validation to confirm the applicability of the results under industrial conditions. These constraints mean that the findings should be interpreted as preliminary.

Further research should emphasize pilot-scale coke oven trials, optimization through beneficiation and blending, as well as detailed seam-based studies within the Tanjung Formation. Investigations into low-carbon technologies, such as biochar or hydrogen-based reduction, are also recommended to align utilization with Indonesia's decarbonization goals.

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